A Dynamic Analysis of the Market for Wide-Bodied Commercial Aircraft

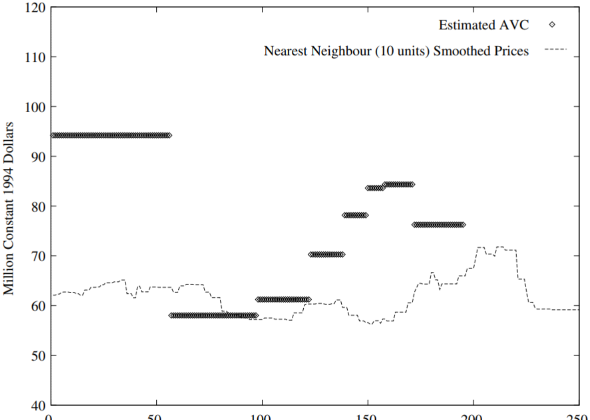
C. Lanier Benkard, presented by Jacob Thompson

March 3, 2019

Motivation

- Empirical: firms often sell jetliners below static marginal cost, in contrast to standard models of firms in competition or oligopoly
- Lockheed L-1011 sold for below average variable cost for entire production run!

REVIEW OF ECONOMIC STUDIES



Motivation cont.

- Policy: airlines are the target of industrial policy
- Past theoretical literature finds that under certain conditions an unrestrained monopoly may pareto-dominate an oligopoly

Empirical Strategy

- Develop dynamic model with learning curves, differentiated products, entry costs, and closed loop strategic interaction
- Estimate the primitives of the model
- Find equilibrium

Theoretical Model

- Dynamic programming problem
- Products indexed by $j \in \mathbb{N}$, time periods indexed by $t \in \mathbb{N}$
- Three state variables per product, experience with product-j
- $E_{jt} \in \mathcal{E}$,
- the product's "type" $\mu_j \in \mathcal{A}$ and
- the product's quality $\xi_{jt} \in \mathcal{X}$
- Sets $\mathcal{E}, \mathcal{A}, \mathcal{X}$ are sets of possible experience levels, product types and product quality levels.

Incumbent's Bellman system

- $$V(i,s,M) = max_{\chi_i^e,\chi_j,q_j \forall j \in \mathcal{J}_i} \{ -\sum_{k=1}^{3} 1\{\chi_i^e = k\} x_k^e$$
$$+ \sum_{j \in \mathcal{J}_i} [\chi_j \Phi_{jt} + (1-\chi_j)\pi_j(i,s,q,M)]$$
$$+\beta \sum_{i',s',M'} V(i',s',M')\mathcal{P}(i',s',M'|i,s,q,M,\chi,\chi^e)\}$$

Incumbent Bellman, cont.

- State variables are: $\mathcal{J}_i$ is set of products owned by firm i,
- $\mathcal{M}$ is aggregate plane demand
- ϕ_{jt} is a random scrap-value for each product
- s_t is a vector whose length equals the number of possible firm-specific state-vectors
- Each element of s_t indicates the number of firms for which the possible state vector is the actual state vector

Incumbent Bellman, cont.

- Control variables are: exit rules, $\chi_{jt} \in \{0, 1\}$
- quantities oproduced $q_{jt} \in \mathbb{R}^+$
- entry rules $x^i_{it} \in \{0, 1, 2, 3\}$, 0, 1, 2, and 3 denote no entry, entry into small, medium, and wide-body jetliners
- $\mathcal{P}$ denotes the transition probabilities for the future states.
- Is a more specific expression of $\beta E_t V(i_{t+1}, s_{t+1}, M_{t+1})$

Potential Entrant's Bellman system

- $$V^e(s, M) = max_{\chi_i^e \in \{0,1,2,3\}} - \sum_{k=1}^{3} 1\{\chi_i^e = k\} x_k^e$$
$$+\beta \sum_{i',s',M'} V(i^e, s', M') \mathcal{P}(i^e, s', M' | s, q, M, \chi, \chi^e)$$

Profit function

$$\pi_j(i, s, q, M) = p_j(i, s, q, M)q_j - c_j(i, q_j)$$

Equilibrium

- Model restricts equilibria to “Markov-perfect Nash Equilibrium(MPE)”
- MPE $\subset$ SPNE; best-response functions function only of payoff relevant state-variables
- Further estrict equilibria further to symmetric equilibria
- Equilibria symmetric if strategies for any two identical firms facing identical states are likewise identical.

Estimating the model

- labor requirements are characterized by:

$$lnL_{lt} = lnA + \theta lnE_t + \gamma lnS_t + \varepsilon_{lt}$$

- L_{lt} is labor input for good l at time t, A is a constant, E_t is experience, ε_{lt} is a plane-specific productivity shock, S_t is line-speed or the production rate.

Learning by doing

- $E_{t+1} = \delta E_t + q_t$ characterizes the evolution of the stock of experience
- This process captures organizational "forgetting"
- Intuition: turnover, lay-offs, and forgetting rarely-repeated tasks can cause effective experience to decline
- Benkard(2000) estimates the monthly depreciation factor $\delta = .96$ for a total yearly depreciation of $.613 = .96^{12}$
- learning parameter θ estimated to be -.63, and γ estimated to be .11, indicating slightly increasing returns to scale.
- to simplify the state space, Benkard defines $\mathcal{E} = \{1, 10, 20, 40, 70, 110, 165\}$

Estimation of Labor requirements

TABLE 1

Cost parameters

Parameter	Explanation	Value
A	Labour cost intercept	7·73 (0·01)
γ	Returns to scale	0·11 (0·17)
δ	Depreciation of experience	0·613 (0·023)
θ	Learning parameter	–0·63 (0·03)
	(Implied learning rate)	36%
W	Wage rate	\$20/h
FC	Fixed costs	\$200 million/year
TCF	Total variable cost/labour cost	6·0
TCC	Total variable cost intercept	36·2
	Cost/plane-size ratio	1·0
x_1^l, x_1^h	Type 1: entry cost distribution	\$2·5–\$3·5 billion
x_2^l, x_2^h	Type 2: entry cost distribution	\$3·3–\$4·6 billion
x_3^l, x_3^h	Type 3: entry cost distribution	\$4·4–\$6·2 billion

Demand for Commercial Aircraft

- Author eschews product-characteristic discrete choice model
- Individual planes often change operators
- Treat aircraft purchases instead as rentals
- nested logit discrete choice model is estimated
- Assumes that aircraft purchases are independent even within the same firm
- Benkard(1996) argues that this assumption is relatively innocuous.
- nested logit includes two groups(nests), new and used (or narrow) planes
- generates more reasonable substitution patterns over standard logit

Estimation cont.

- Utility of a plane is denoted
  $u_{ijt} = x_{jt}\beta - \alpha p_{jt} + \xi_{jt} + \zeta_{igt} + (1 - \lambda)\varepsilon_{ijt}$
- x_{jt} are observed qualities of the plane
- ξ_{jt} are unobserved qualities of plane
- ζ_{igt} are unobserved group-specific tastes
- ε_{ijt} are group-plane-specific tastes

Estimation cont.

- Use GMM with an optimal weighting matrix with the following moment restriction:

$$E[\xi_{jt}|Z_{jt}, \theta_0] = 0$$

-Instruments include plane characteristics, wage rates, price of aluminium, and a model's time since rollout

Markov chain for aircraft demand

TABLE 3

Demand and other parameters

Parameter	Explanation	Value
λ	Group corr. parameter	0·77 (0·18)
α	Price coefficient	−0·024 (0·002)
μ	Discrete plane types (small, medium, large)	$\{-2{\cdot}6, -2{\cdot}2, -1{\cdot}6\}$
$P(\mu^e)$	Entry type distribution (small, medium, large)	$(0{\cdot}50 \quad 0{\cdot}38 \quad 0{\cdot}12)$
ξ	Discrete plane qualities	$\{-0{\cdot}90, -0{\cdot}40, 0{\cdot}11, 0{\cdot}61\}$
$\Delta\xi$	Transition matrix for quality	$\begin{pmatrix} 1{\cdot}00 & 0{\cdot}04 & 0{\cdot}033 & 0{\cdot}000 \\ 0{\cdot}00 & 0{\cdot}44 & 0{\cdot}233 & 0{\cdot}200 \\ 0{\cdot}00 & 0{\cdot}48 & 0{\cdot}667 & 0{\cdot}800 \\ 0{\cdot}00 & 0{\cdot}04 & 0{\cdot}067 & 0{\cdot}000 \end{pmatrix}$
M	Discrete market sizes	(10,339 10,929 11,519)
ΔM	Transition matrix for market size	$\begin{pmatrix} 0{\cdot}895 & 0{\cdot}143 & 0{\cdot}000 \\ 0{\cdot}105 & 0{\cdot}786 & 0{\cdot}200 \\ 0{\cdot}000 & 0{\cdot}071 & 0{\cdot}800 \end{pmatrix}$
β	Firm's discount factor	0·925
(Φ^l, Φ^h)	Range of scrap values	$(\$300m, \$700m)$

Figure 2:

Simulation results

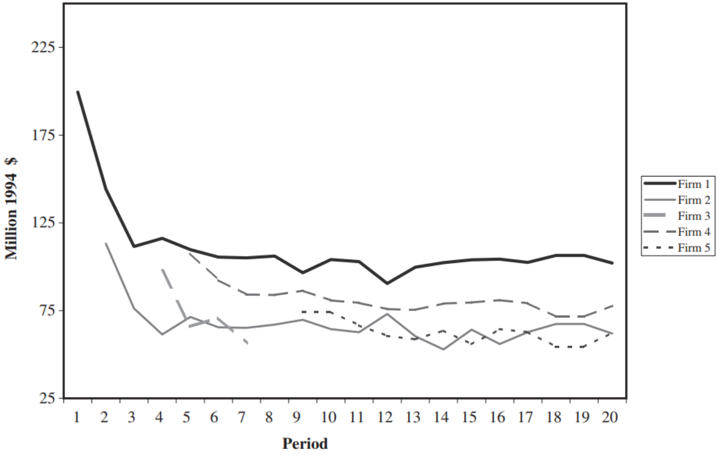


FIGURE 5
Twenty-year simulation: prices

Figure 3:

Simulation results cont.

604 REVIEW OF ECONOMIC STUDIES

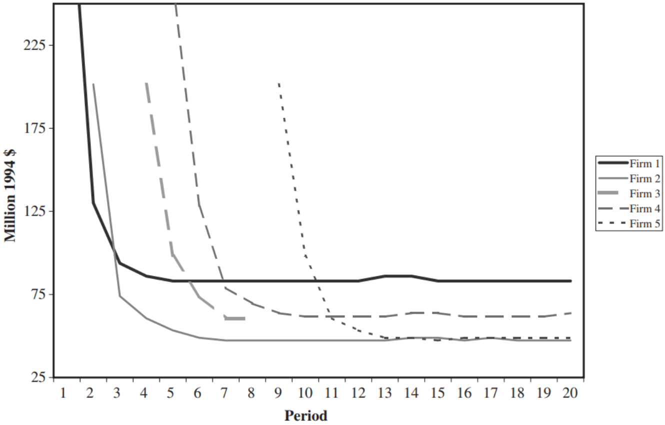


FIGURE 6

Twenty-year simulation: cost curves

Figure 4:

Simulation results cont.

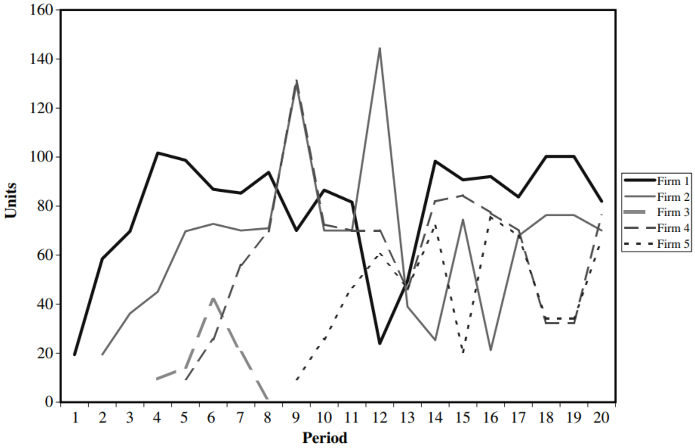


FIGURE 7

Twenty-year simulation: units produced

Figure 5:

Alternative market structures

- True market structure is compared to multi-product monopolist and multi-product social planner
- Unrestricted monopolist produces greater surplus than the oligopolistic market
- Consumers better off under actual market structure, but firms far worse off
- Consumers even better off under Social plannner but firm worse off
- Result of increasing returns to scale created by learning curve

Anti-trust policy

TABLE 7

Statistics from 10,000 *industry simulations under alternative policies*

Maximum concentration:	100%	60%	51%
Concentration ratios:	(Invariant distribution)		
1-Firm/plane	0·396	0·392	0·385
S.D.	0·102	0·094	0·081
2-Firm/plane	0·692	0·690	0·688
S.D.	0·109	0·107	0·103
Consumer surplus:			
Mean	135,373	134,917	133,895
S.D.	7040	7268	7488
Producer surplus:			
Mean	42,335	42,306	42,320
S.D.	3769	3776	3785
Total surplus:			
Mean	177,708	177,223	176,215
S.D.	10,441	10,645	10,832

Figure 6:

Anti-trust policy cont.

- Note that actual concentration ratios do not change substantially
- Primary result is reduction in supply by dominant firm
- Table 9 re-simulates the model under alternative parameterizations
- Only discount rate creates problems; larger β causes more entry

Summary

- Dynamic oligopoly with learning curve
- Predicts many observed features of commercial jet industry
- Concrete policy implications for anti-trust enforcement and litigation